International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 9, Issue 3, Jun 2019, 1133-1142

•Journal Publications •Research Consultancy

EXPERIMENTAL ANALYSIS OF THE INFLUENCE OF LUBRICATION STRATEGY AND MACHINING PARAMETERS ON SURFACE ROUGHNESS & TOOL WEAR IN MILLING OF TI- 6AL-4V USING TAGUCHI BASED GREY RELATIONAL ANALYSIS

PRASAD A. JADHAV[1] & Dr. R. DEIVANATHAN[2]

[1]*Research Scholar, VIT University, Chennai, Tamil Nadu, India*

[2]*Associate Professor, VIT University, Chennai, Tamil Nadu, India*

ABSTRACT

Suddenly increased demand of titanium in Aerospace and medical industry is attracting the focus towards titanium machining now a days. Titanium in spite of several good properties like high strength to weight ratio and excellent corrosion resistance, it is one of the difficult to cut material because of its low thermal conductivity and high reactiveness at elevated temperature. Ninety percent of the aerospace parts require milling operation hence this paper focuses on milling operation. Titanium milling is constrained by low speed, feed and depth of cut during machining, low MRR, high temperature, costly tooling, and shorter tool life and requires high pressure coolant to be sprayed to cutting zone. All above constraints makes titanium difficult to cut and contribute towards increased environmental burden. Therefore it is necessary to find sustainable machining methods for titanium which will reduce coolant consumption and increase tool life without sacrificing the surface quality.

This paper therefore focuses on experimental analysis using Taguchi based GRA to find influence of various factors on tool wear and surface roughness. Method of grey relational analysis is used for multi objective optimization. Taguchi L16 orthogonal array is used and flood cooling and MQL strategy is compared. The optimum combination consists of MQL at 200ml/hr flow rate, Speed 1000 rpm, Feed 0.06 mm/tooth and depth of cut of 0.6mm. At this combination the values of tool wear and surface roughness are 0.068mm and 0.271 micro meter respectively. The TiALN coated carbide milling inserts used for experimentation Cooling strategy is also taken as one of the factors for Study.

KEYWORDS: MQL, GRA, Milling & Taguchi

Received: Mar 30, 2019; **Accepted**: Apr 20, 2019; **Published**: May 25, 2019; **Paper Id**.: IJMPERDJUN2019121

Original Article

INTRODUCTION

Various inherent properties of Ti-6al-4v which include corrosion resistance, thermal resistance, high load bearing capacity and high strength to weight ratio makes titanium a useful material for aerospace applications[2]. High temperature is generated during titanium machining due to high friction and deformation which tends to the build-up edge formation on the tool and results in rapid tool wear. Low plasticity of titanium alloy increases stress on cutting tool which results in undercut and variation of chip thickness. All above facts outlines the fact of using high pressure coolant because a good cooling system can reduce temperature up to 30%[1-2]. The need of cryogenic cooling was outlined by[1] but it has its own environmental limitations. Therefore there is need of improved and thermally enhanced and environmental friendly cooling technique MQL.

Attempts have been made to characterize various lubrication conditions in milling of Ti-6al-4v by[3] and compared the output of Dry, Jet and MQL technique and found lowest tool wear in MQL condition. MQL is considered as near dry machining and is compared with the dry, wet and cryogenic machining. Liquid carbon dioxide is used as coolant in study of cryogenic machining and it has been found increased tool life as flow increases as compared to MQL[4]. Using of Graphite Nanoplatelets in MQL fluid significantly reduces tool wear as compared with cryogenic machining with Liquid Nitrogen. As Ln2 causes thermal gradient on surface of cutting tool and hardening of titanium alloy the MQL turned out to be a beneficial method[5].

Minimum quantity lubrication is applied in machining of Ti-6al-4v to study its effectiveness[6-9]. Feasible conditions for MQL application in milling of Ti-6al-4V using cemented carbide tool were studied and found significant increase in tool life and reduction in average roughness value as per results of SEM/EDS analysis by[6].The oil supply rate in MQL plays an important role. Increasing the oil flow rate from 2ml/hr to 14ml/hr reduces cutting force and surface roughness[7]. Three types of tools vizTiAl coated, multilayer TiAlN coated and Single layer TiAlN coated has been studied for Ra and Tool life and single layer TiAlN tool is giving better toll life and minimum Ra [8]. Micro hardness and Ra has been studied by[9] and found that speed and feed has highest impact on Ra whereas micro hardness is influenced by feed per tooth[9].

Objective of this study is to investigate effect of major influencing parameters (Lubrication Condition, Speed, Feed and depth of cut on Flank wear and Surface roughness as well as to find optimum combination of above parameters using Taguchi based Grey relational Analysis.

Taguchi based GRA[10-16] is a method of multi-objective optimization. In this method multiple response is converted to single objective i.e. Grey relational grade which is then used for optimization. ANOVA plays important role in finding significant parameter and optimum level in GRA.

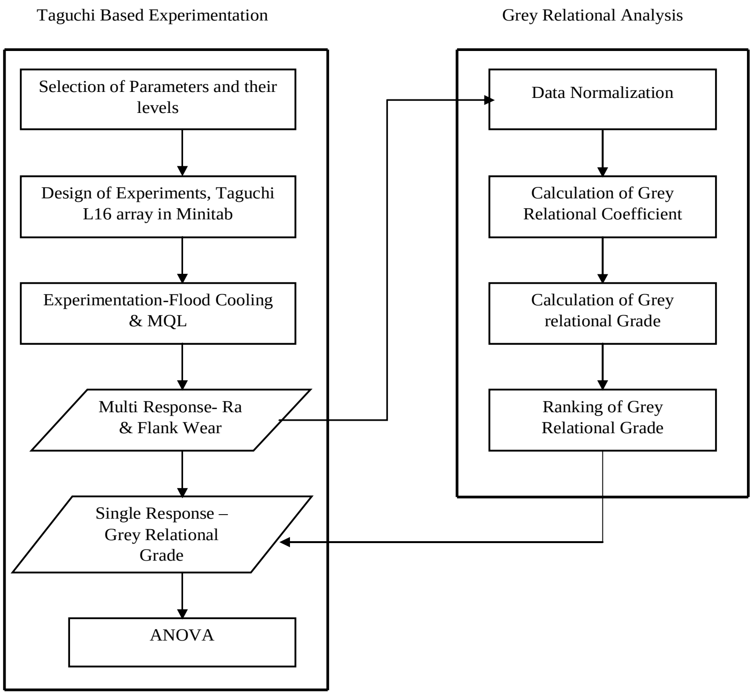

Figure 1: Procedure of Taguchi Based GRA Modified [10]

EXPERIMENTATION AND TEST RESULTS

The end milling experiments were carried out on Ti-6Al-4V(ASTM B 256) alloy of 100x90x8 mm size whose chemical composition is shown in table 1. The tests were performed on Leadwell V40 VMC under flood and MQL cooling environments. Pre-machining of workpiece is done prior to final experimentation to remove surface irregularities. Φ 16mm milling cutter with two APKT100308PDTR TiALN coated inserts of company YG1 are used. New inserts have been used of every experiment. MQL oil used is vegetable base neat cutting oil manufactured by Lubeco Green Fluids, Pune. The oil is having viscosity of 35 to 40 cst with flash point greater than 200ºC and is free from EP additives. The experimental setup using flood cooling and MQL is shown in figure 2 & 3 respectively. Radial depth of cut is maintained constant 8mm for all the experiment and MQL nozzle is mounted 85mm away from the centre of the tool.

Table 1: Chemical Composition of Ti-6AL-4V[7]

Composition	Ti	Al	V	Fe	C	N	H	O
Weight(%)	Reminder	5.5-6.8	3.5-4.5	0.30	0.10	0.05	0.015	0.20

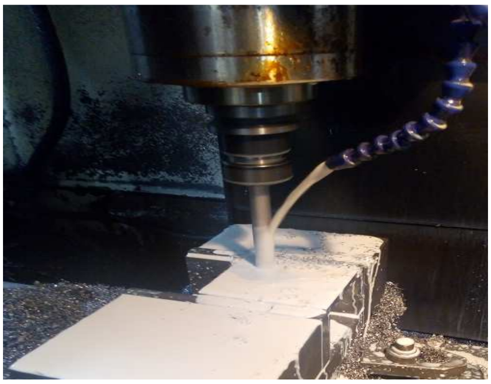

Figure 2: Experiments with Flood Cooling

Figure 3: Experiments with MQL

Taguchi Design of experiments is used to formulate L16 orthogonal array using Minitab software. The parameters are selected based upon the recommendation of tool Manufacturer.

Table 2: Parameters for Experimentation

Parameter	Level 1	Level 2	Level 3	Level 4
Lubrication Strategy	**Flood Cooling**	**MQL F1**	**MQL F2**	**MQL F3**
Speed(rpm)	550	700	850	1000
Feed(mm/tooth)	0.06	0.08	0.10	0.12
Axial Depth of Cut(mm)	0.2	0.4	0.6	0.8

For MQL the Mist pressure is kept constant at 3 bar and stand-off distance is 85mm.

- MQL F1= MQL with oil flow rate of 100 ml/hr,
- MQL F2= MQL with oil flow rate of 150 ml/hr,
- MQL F3= MQL with oil flow rate of 200 ml/hr

Experiments were performed as per Taguchi L16 array and fresh workpiece and tool is used for every experimental run. Mahr surface roughness tester (figure 5) is used to measure Ra value and to measure flank wear is measured with the help of Rapid- I(figure 4) vision measuring instrument is used. Experimental results are shown in Table 3.

Figure 4: Rapid- I Vision Measuring Instrument

Figure 5: Mahr Surface Roughness Tester

Table 3: Experimental Results for L16 OA

Run No	Process Parameters				Response	
	Lubrication Strategy	Speed (Rpm)	Feed (mm/tooth)	Depth of Cut(mm)	Ra (micron)	Vbmax (mm)
1	Flood	550	0.06	0.2	0.4095	0.1121
2	Flood	700	0.08	0.4	0.3685	0.12135
3	Flood	850	0.1	0.6	0.359	0.136
4	Flood	1000	0.12	0.8	0.473	0.15035
5	MQL F1	550	0.08	0.6	0.419	0.10665
6	MQL F1	700	0.06	0.8	0.2745	0.0662
7	MQL F1	850	0.12	0.2	0.5065	0.0588
8	MQL F1	1000	0.1	0.4	0.3745	0.08455
9	MQL F2	550	0.1	0.8	0.39	0.02755
10	MQL F2	700	0.12	0.6	0.321	0.05695
11	MQL F2	850	0.06	0.4	0.288	0.0533
12	MQL F2	1000	0.08	0.2	0.4355	0.03925
13	MQL F3	550	0.12	0.4	0.41	0.0321
14	MQL F3	700	0.1	0.2	0.4925	0.0258
15	MQL F3	850	0.08	0.8	0.41	0.0471
16	MQL F3	1000	0.06	0.6	0.271	0.06795

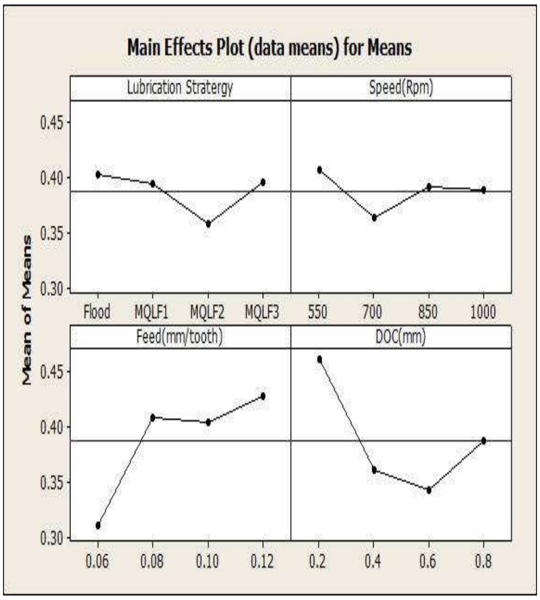

Figure 6: Main Effects Plot for Ra

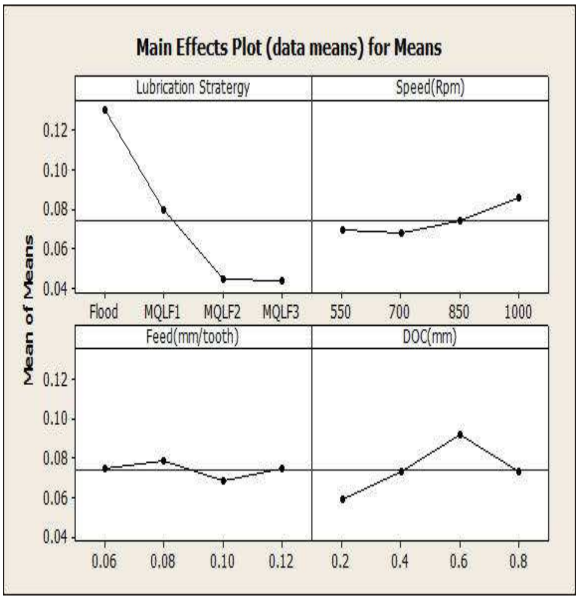

Figure 7: Main Effects Plot for Vbmax

From the main effect plots for surface roughness it is clear that feed rate followed by depth of cut has major influence on Ra value followed by speed and lubrication Strategy for given combination of experiments. Surface roughness increases with increase in feed and found maximum at feed of 0.12 mm/tooth. From figure 6 effect of depth of cut cannot be predicted precisely because of unpredictable variation. Flank wear is influenced by the lubrication Strategy followed by depth of cut. From figure 7 it is clear that Flank wear is minimum in MQL condition and found lowest at MQL with oil flow rate of 200ml/hr and depth of cut of 0.2mm.

However tool wear and Surface roughness are interdependent therefore it is necessary to study effect of different parameters simultaneously. Grey relational analysis is one of the best alternative in such a case.

Grey Relational Analysis

GRA was developed by Chinese professor Julong Deng in 1982 which is based on Grey system theory. It works by defining situations with no information as black and situations with perfect information are white however neither of this idealizes situation in real world problem in fact situations between these two extreme cases is termed as Grey and therefore a grey system is a system in which a part of information is known and part of information is unknown. Thus Grey relational analysis doesn't provide a best solution but it provides techniques to find good solution.

In this paper both the response parameters Ra and Vbmax are of smaller-is-better type means smaller the value of response we will get better machining conditions.

Step 1: Data Normalization

Data is to be normalized in 0 and 1 using equation (1) to reduce variability that is converting data into comparable data. Here, Ra and Vbmax are normalized in the range between zero and one which is called as grey relational generation.

$$x_i^*(k) = \frac{Max x_i(k) - x_i(k)}{Max x_i(k) - Min x_i(k)} \tag{1}$$

Here, i= 1,2……16, k= 1,2 as the response are two, Max $x_i(k)$ is maximum value of $x_i(k)$ and Min $x_i(k)$ is minimum value of $x_i(k)$, $x_i^*(k)$ represents value after data processing and x denotes desired value. The normalized values are shown in Table 4

Step 2: Grey Relational Coefficient Calculation

GRA coefficient is calculated using equation (2)

$$\xi_i(k) = \frac{\Delta_{min} + \xi \Delta_{max}}{\Delta_{0i}(k) + \Delta_{max}} \tag{2}$$

In above equation $\xi$is identification coefficient and generally taken as 0.5, Δ_{0i} is a deviation sequence given by, $\Delta_{0i} = \|x_0(k) - x_i(k)\|$

Where $x_0(k)$ and $x_i(k)$ are refrence and comparibility sequence respectively.Δ_{min}andΔ_{max} are minimum and maximum values of deviation sequence Δ_{0i}

Step 3: Finding Grey Relational Grade

To convert multi objective problem into single objective problem the Grey relational Grade required to be calculated using equation no (3) which can be then used in Taguchi method.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \tag{3}$$

Here, γ_i is a Grey relational grade and n is number of responses.The grey relational grade equivalent to each experiment is represented in table 4. Higher the grey relational grade there is higher possibility of respective experimental combination to be closer to ideal normalized value. Corresponding grey relational grades are shown in Table 5.

Table 4: Normalized Values of Ra and Vbmax

Run No	Lubrication Strategy	Speed (rpm)	Feed (mm/tooth)	Depth of Cut(mm)	Ra	Vbmax	Normalized Ra	Normalized Vbmax
1	Flood	550	0.06	0.2	0.4095	0.1121	0.4118896	0.30710558
2	Flood	700	0.08	0.4	0.3685	0.12135	0.58598726	0.232838218
3	Flood	850	0.1	0.6	0.359	0.136	0.62632696	0.115214773
4	Flood	1000	0.12	0.8	0.473	0.15035	0.14225053	0
5	MQL F1	550	0.08	0.6	0.419	0.10665	0.37154989	0.350863107
6	MQL F1	700	0.06	0.8	0.2745	0.0662	0.985138	0.675632276
7	MQL F1	850	0.12	0.2	0.5065	0.0588	0	0.735046166
8	MQL F1	1000	0.1	0.4	0.3745	0.08455	0.56050955	0.528301887
9	MQL F2	550	0.1	0.8	0.39	0.02755	0.49469214	0.985949418
10	MQL F2	700	0.12	0.6	0.321	0.05695	0.78768577	0.749899639
11	MQL F2	850	0.06	0.4	0.288	0.0533	0.92781316	0.779205138
12	MQL F2	1000	0.08	0.2	0.4355	0.03925	0.3014862	0.89201124
13	MQL F3	550	0.12	0.4	0.41	0.0321	0.40976645	0.949417904
14	MQL F3	700	0.1	0.2	0.4925	0.0258	0.05944798	1
15	MQL F3	850	0.08	0.8	0.41	0.0471	0.40976645	0.828984344
16	MQL F3	1000	0.06	0.6	0.271	0.06795	1	0.661581694

Table 5: GRA Coefficient and Grey Relational Grade for Response Parameters

Run No	Lubrication Strategy	Speed (rpm)	Feed (mm/tooth)	Depth of Cut(mm)	Ra	Vbmax	GRA Coeff. Ra	GRA Coeff. Vbmax	GRG	Rank
1	Flood	550	0.06	0.2	0.4095	0.1121	0.459512	0.419149	0.43933	14
2	Flood	700	0.08	0.4	0.3685	0.12135	0.547038	0.394583	0.47081	12
3	Flood	850	0.1	0.6	0.359	0.136	0.572296	0.361067	0.466682	13
4	Flood	1000	0.12	0.8	0.473	0.15035	0.368256	0.333333	0.350795	16
5	MQL F1	550	0.08	0.6	0.419	0.10665	0.443086	0.435109	0.439097	15
6	MQL F1	700	0.06	0.8	0.2745	0.0662	0.971134	0.606525	0.78883	2
7	MQL F1	850	0.12	0.2	0.5065	0.0588	0.333333	0.653634	0.493484	11
8	MQL F1	1000	0.1	0.4	0.3745	0.08455	0.532203	0.514563	0.523383	10
9	MQL F2	550	0.1	0.8	0.39	0.02755	0.49736	0.972667	0.735014	4
10	MQL F2	700	0.12	0.6	0.321	0.05695	0.701937	0.666577	0.684257	5
11	MQL F2	850	0.06	0.4	0.288	0.0533	0.87384	0.693679	0.78376	3
12	MQL F2	1000	0.08	0.2	0.4355	0.03925	0.417183	0.822384	0.619783	8
13	MQL F3	550	0.12	0.4	0.41	0.0321	0.458617	0.90813	0.683374	6
14	MQL F3	700	0.1	0.2	0.4925	0.0258	0.347089	1	0.673545	7
15	MQL F3	850	0.08	0.8	0.41	0.0471	0.458617	0.745139	0.601878	9
16	MQL F3	1000	0.06	0.6	0.271	0.06795	1	0.596361	0.798181	1

ANALYSIS OF VARIANCE

ANOVA is the way to find out whether the conducted experiments significant or not that is investigates which machining parameter affects the performance characteristics.

Table 6: Response Table for Means of Grey Relational Grade

Level	Lubrication Strategy	Speed(Rpm)	Feed(mm/tooth)	DOC(mm)
1	0.4319	0.5742	0.7025	0.5565
2	0.5612	0.6544	0.5329	0.6153
3	0.7057	0.5865	0.5997	0.5971
4	0.6892	0.5730	0.5530	0.6191
Delta	0.2738	0.0813	0.1696	0.0626
Rank	1	3	2	4

Table 7: Analysis of Variance for GRG, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Lubrication Strategy	3	0.195455	0.195455	0.065152	9.74	0.047
Speed(Rpm)	3	0.017982	0.017982	0.005994	0.90	0.535
Feed(mm/tooth)	3	0.068761	0.068761	0.022920	3.43	0.169
DOC(mm)	3	0.009852	0.009852	0.003284	0.49	0.713
Error	3	0.020076	0.020076	0.006692		
Total	15	0.312127				

S = 0.0818046R-Sq = 93.57%R-Sq(adj) = 67.84%

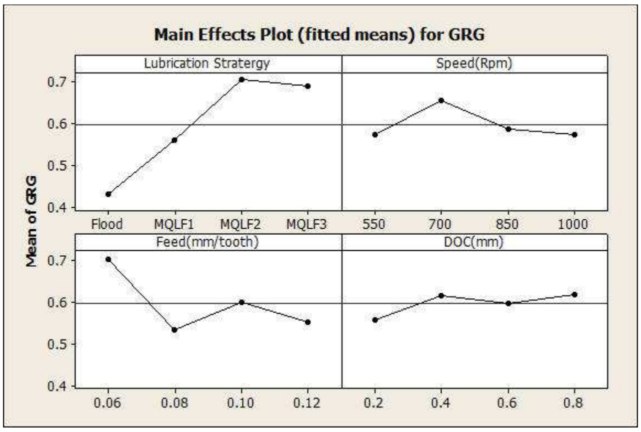

Figure 8: Main Effects Plot for GRG

Response table for means Table 6 shows that delta is higher for lubrication strategy followed by Feed, Speed and depth of cut respectively. Table 7 shows ANOVA using adjusted ss square test in which larger F value is for lubrication strategy and P value is 0.047 which is less than 0.05 at 95% confidence level which depicts that lubrication strategy has significant effect on GRG.

CONCLUSIONS

The present work is aimed towards finding the feasibility of applying MQL in end milling of Ti-6AL-4V alloy as an alternative to conventional flood cooling as flood cooling comes with various environmental and sustainability concerns. It is found in the present study that MQL reduces Surface roughness as well as tool wear when applied with proper oil flow rate. ANOVA of Grey relational Grade has performed which shows that Lubrication strategy affects Grey Relational Grade significantly and MQL with oil flow rate of 150 to 200ml/hr gives highest grey relational Grade which means better is the combined response that is Surface roughness and Flank Wear. This is because of the better penetration of mist in cutting zone to reduce the machining temperature compared to flood cooling.

It is also concluded that Vegetable oil based MQL can improve the machining performance when applied properly and which can be sustainable alternative.

According to grey relational analysis experiment number 16 turned out to be optimum for minimum roughness and flank wear where Speed is 1000 rpm, feed 0.06 mm/tooth, depth of cut of 0.6 mm and lubrication strategy is MQL with oil flow rate of 200ml/hr.

ACKNOWLEDGEMENT

This work is supported by Esteem Engineers, Bhosari MIDC, Pune and authors are very much thankful for cooperation from them.

REFERENCES

1. *Pramanik, "Problems and solutions in machining of titanium alloys," Int. J. Adv. Manuf. Technol., vol. 70, no. 5–8, pp. 919–928, 2014.*
2. *Pramanik and G. Littlefair, "Machining of titanium alloy (Ti-6Al-4V)-theory to application," Mach. Sci. Technol., vol. 19, no. 1, pp. 1–49, 2015.*
3. *E. Vazquez, J. Gomar, J. Ciurana, and C. A. Rodríguez, "Analyzing effects of cooling and lubrication conditions in micromilling of Ti6Al4V," J. Clean. Prod., vol. 87, no. 1, pp. 906–913, 2015.*
4. *Elzanaty, H. (2014). Effect of different Si content on the mechanical properties in Al-based alloy. International Journal of Research in Engineering & Technology (IMPACT: IJRET), 2(7), 49-54.*
5. *M. I. Sadik, S. Isakson, A. Malakizadi, and L. Nyborg, "Influence of Coolant Flow Rate on Tool Life and Wear Development in Cryogenic and Wet Milling of Ti-6Al-4V," Procedia CIRP, vol. 46, pp. 91–94, 2016.*
6. *K. H. Park, M. A. Suhaimi, G. D. Yang, D. Y. Lee, S. W. Lee, and P. Kwon, "Milling of titanium alloy with cryogenic cooling and minimum quantity lubrication (MQL)," Int. J. Precis. Eng. Manuf., vol. 18, no. 1, pp. 5–14, 2017.*
7. *Szoka, A. N. N. A., Gajowiec, G., Serbinski, W. A. L. D. E. M. A. R., & Zielinski, A. N. D. R. Z. E. J. (2016). Effect of surface state and stress on an oxidation of the zircaloy-2 alloy. Intl J Manag Inform Techn Eng, 4, 55-64.*
8. *U. Garcia and M. V. Ribeiro, "Ti6Al4V Titanium Alloy End Milling with Minimum Quantity of Fluid Technique Use," Mater. Manuf. Process., vol. 31, no. 7, pp. 905–918, 2016.*
9. *Abbas, A. R., Hebeatir, K. A., & Resan, K. K. (2018). Effect of CO2 Laser on Some Properties of NI46TI50CU4 Shape Memory Alloy. International Journal of Mechanical and Production Engineering Research and Development, 8(02), 451-460.*
10. *X. J. Cai, Z. Q. Liu, M. Chen, and Q. L. An, "An experimental investigation on effects of minimum quantity lubrication oil supply rate in high-speed end milling of Ti-6Al-4V," Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., vol. 226, no. 11, pp. 1784–1792, 2012.*
11. *W. Polini and S. Turchetta, "Cutting force, tool life and surface integrity in milling of titanium alloy Ti-6Al-4V with coated carbide tools," Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., vol. 230, no. 4, pp. 694–700, 2016.*
12. *SOLIMAN, H. N., & RIZK, A. (2014). Surface structure, composition and hardenability of Cu-10Ni-2Al alloy developed in a magnetron sputtering system. IMPACT: International Journal of Research in Applied, Natural and Social Sciences (IMPACT: IJRANSS), 2(12), 49-58.*

13. H. Hassanpour, M. H. Sadeghi, H. Rezaei, and A. Rasti, "Experimental Study of Cutting Force, Microhardness, Surface Roughness, and Burr Size on Micromilling of Ti6Al4V in Minimum Quantity Lubrication," Mater. Manuf. Process., vol. 31, no. 13, pp. 1654–1662, 2016.

14. Kuo, Y., Yang, T., & Huang, G. W. (2008). The use of grey relational analysis in solving multiple attribute decision-making problems. Computers and Industrial Engineering, 55(1), 80–93. https://doi.org/10.1016/j.cie.2007.12.002

15. Lin, C. L. (2007). Materials and Manufacturing Processes Use of the Taguchi Method and Grey Relational Analysis to Optimize Turning Operations with Multiple Performance Characteristics Use of the Taguchi Method and Grey Relational Analysis to Optimize Turning Operations wit, (September 2013), 37–41. https://doi.org/10.1081/AMP-120029852

16. Panda, A., Sahoo, A. K., & Rout, A. K. (2016). Multi-attribute decision making parametric optimization and modeling in hard turning using ceramic insert through grey relational analysis: A case study. Decision Science Letters, 5, 581–592. https://doi.org/10.5267/j.dsl.2016.3.001

17. Ramu, I., Srinivas, P., & Vekatesh, K. (2018). Taguchi based grey relational analysis for optimization of machining parameters of CNC turning steel 316. IOP Conference Series: Materials Science and Engineering, 377(1). https://doi.org/10.1088/1757-899X/377/1/012078

18. Rizvi, S. A., & Tewari, S. P. (2017). Multi Objective Optimization by Application of Taguchi Based Grey Relational Analysis for GMA Welding of IS2062 Structural Steel. Mechanics and Mechanical Engineering, 21(3), 717–729.

19. Sylajakumari, P. A., Ramakrishnasamy, R., & Palaniappan, G. (2018). Taguchi grey relational analysis for multi-response optimization of wear in co-continuous composite. [19]Materials, 11(9), 1–17. https://doi.org/10.3390/ma11091743

20. Vinayagamoorthy, R., & Xavior, M. A. (2014). Parametric Optimization on Multi-Objective Precision Turning Using Grey Relational Analysis. Procedia Engineering, 97, 299–307. https://doi.org/10.1016/j.proeng.2014.12.253